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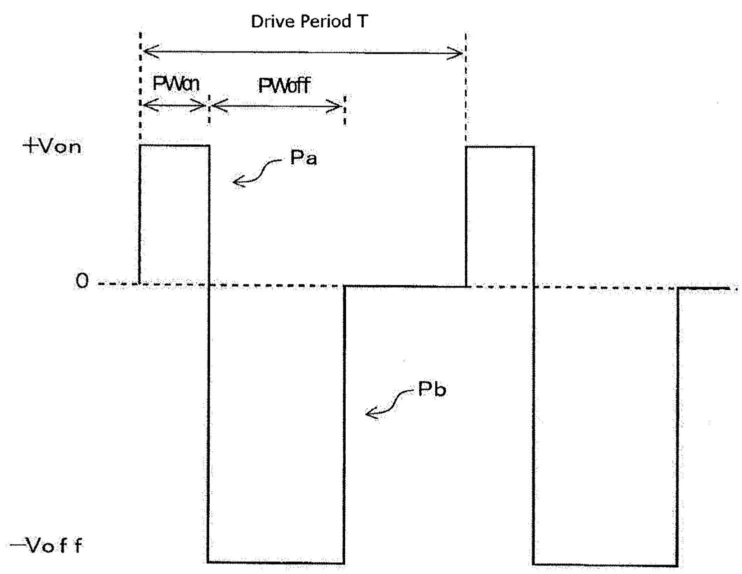
(54) Droplet injection apparatus and method for driving droplet injection apparatus

(57) A problem to be solved by the present invention is to provide a droplet injection apparatus controlling the driving in such a way that an ink injection operation is sequentially performed by time division by dividing all the channels into two or more groups, each being formed of the channels away from one another with one or more channels placed therebetween, and applying a drive signal to each group, the ink has a viscosity of less than 5.0×10^{-3} Pa·sec, the drive signal contains a first pulse formed as a rectangular wave and increasing the volume of the channel and restoring the volume to the original volume after a lapse of a given period of time and a second pulse formed as a rectangular wave and reducing the volume of the channel and restoring the volume to the original volume after a lapse of a given period of time, and the ratio of a voltage Von of the first pulse to a voltage Voff of the second pulse is $0.5 \leq |Von/Voff| \leq 0.8$.

FIG. 3



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Description

BACKGROUND OF THE INVENTION

1. Field of the Invention

[0001] The present invention relates to droplet injection apparatuses and methods for driving the droplet injection apparatus and, in particular, to a droplet injection apparatus and a method for driving the droplet injection apparatus, the apparatus and the method that can inject low-viscosity ink with stability without being affected by the injection performed by an adjacent nozzle.

2. Description of the Related Art

[0002] A droplet injection apparatus having a recording head that injects ink in a channel which is a pressure generating chamber as a minuscule ink droplet out of a nozzle is widely used as an ink-jet recording apparatus that records and forms a desired ink-jet image by making an ink droplet land on a recording medium such as recording paper. In the field of such an ink-jet recording apparatus, there has been a growing need for ink-jet ink for industrial use, and injection of inks having various properties is desired. In particular, in recent years, there has been a tremendous increase in interest in water-based ink using water as a main solvent out of consideration for the environment. The ink viscosity of the water-based ink is often low due to the properties of water.

[0003] Since the viscous drag of low-viscosity ink having a viscosity of less than 5.0×10^{-3} Pa·sec (pascal seconds) in the channel of the recording head is reduced, the meniscus in the nozzle vibrates greatly. As a result, when the recording head injects the ink in the channel out of the nozzle by driving an actuator, the air is sometimes sucked into the nozzle during injection.

[0004] In particular, this phenomenon occurs more noticeably when a recording head in use is a recording head of shear mode type that sequentially injects the ink in channels out of nozzles by using a partition wall shared by adjacent channels as an actuator and driving the partition walls, each corresponding to channels arranged with one another, by time division.

[0005] That is, since the recording head of shear mode type cannot inject ink droplets concurrently from the adjacent channels, when the ink in one channel is injected out of the nozzle, the ink in the channel adjacent to the one channel is not injected at the same time. However, in actuality, the pressure is generated also in the ink in the adjacent channel as a result of the partition wall of the channels being deformed and driven due to the injection of the ink droplet, and the meniscus in the nozzle adjacent to the injection channel is extruded. When the amount of extrusion of meniscus is large, the air is sucked into the nozzle when the meniscus is drawn into the nozzle again, making it impossible to continue stable injection.

[0006] When the ink droplet is continuously injected from the channel adjacent to the channel that injects the ink droplet, the extrusion of the meniscus presents no problem because this extrusion is cancelled by the ink droplet injection operation. However, this extrusion becomes a large problem when a channel adjacent to the channel that injects an ink droplet is a non-injection channel that does not inject an ink droplet. In particular, in a driving pattern in which an injection channel and a non-injection channel are arranged alternately, the non-injection channel is affected by the drive pressure of the injection channels on both sides, making it most difficult to realize stable injection.

[0007] FIG. 9 depicts the time change in the amount of extrusion of meniscus in a nozzle in a non-injection channel when 3-cycle driving (driving on alternate channels) is performed in the recording head of shear mode type by using two types of ink: ink having a viscosity of 3.8×10^{-3} Pa·sec (= 3.8 cp) and ink having a viscosity of 5.7×10^{-3} Pa·sec (= 5.7 cp).

[0008] As shown in FIGs. 5A to 5C, 3-cycle driving is one of drive methods for driving the recording head of shear mode type, the methods by which all the channels 31 are divided into three groups: group A, group B, and group C by treating channels 31 on every two lines as one group and the channels 31 are driven on a group-by-group basis by time division. FIG. 9 depicts the time change in the amount of extrusion of meniscus of a specific non-injection channel (an odd-numbered channel) of the group A when even-numbered channels of the channels 31 are driven as injection channels that perform ink injection in the order of the group A, the group B, and the group C (A cycle $\rightarrow$ B cycle $\rightarrow$ C cycle). Here, the even-numbered channel is assumed to be an injection channel. Therefore, although the odd-numbered channel itself of the channels of the group A is a non-injection channel, since the channels on both sides thereof, the channels of the group B and the group C, are even-numbered channels and injection channels, the odd-numbered channel of the channels of the group A is easily affected by these injection channels.

[0009] As is clear from FIG. 9, the lower the viscosity of ink, the larger the amount of extrusion of meniscus. When the amount of extrusion of meniscus is increased, the risk of sucking the air into the nozzle when the meniscus is drawn into the nozzle is increased. In actual printing, all the channels are not always driven, and, even with 3-cycle driving, there may be a non-injection channel placed between the injection channels as described above depending on printing data. Thus, it is impossible to ignore the sucking of the air due to an increase in the amount of extrusion of meniscus in the nozzle in the non-injection channel.

[0010] In the past, in Patent Document 1, a method by which a channel that performs injection and a dummy channel that does not perform injection are alternately provided in order to reduce the influence on a channel adjacent to the channel that injects ink has been disclosed. However, with this method, it is difficult to increase the channel density (nozzle density). This makes it difficult to increase printing productivity and improve image quality.

[0011] Moreover, Patent Document 2 discloses a technique of setting the voltage ratio of a first pulse to a second pulse at 1.2 or more but 5.0 or less to stabilize the meniscus at the time of high speed driving. However, this technique is aimed at reducing meniscus vibration in a nozzle after ink is injected out of the nozzle and does not give consideration to the influence of the meniscus of an adjacent channel when driving is performed by using, in particular, low-viscosity ink having a viscosity of less than 5.0×10^{-3} Pa·sec. With this technique, it is impossible to solve the problem of sucked air caused by the extrusion of the meniscus of a nozzle of a non-injection channel adjacent to an injection channel when time division driving is performed by 3-cycle driving by using a recording head of shear mode type as described earlier.

Patent Document

[0012]

[Patent Document 1] Japanese Unexamined Patent Application Publication No. 2000-15802
[Patent Document 2] Japanese Unexamined Patent Application Publication No. 2001-310461

SUMMARY OF THE INVENTION

[0013] The present invention has been made in view of the circumstances described above, and an object thereof is to provide a droplet injection apparatus and a method for driving the droplet injection apparatus, the apparatus and the method that can inject an ink droplet from a recording head with stability by stabilizing the vibration of the meniscus of a nozzle that does not perform injection, the nozzle adjacent to a nozzle that performs injection, when an ink droplet is injected from a recording head of shear mode type by time division driving by using low-viscosity ink, the recording head of shear mode type that causes shear deformation of a partition wall shared by adjacent channels as an actuator.

[0014] Other problems of the invention will be made clear by the following description.

[0015] The above-described problems will be solved by the following aspects of the invention.

[0016] A first aspect of the invention provides a droplet injection apparatus comprising: a recording head ,including a plurality of nozzles injecting ink droplets, a plurality of channels, each communicating with a corresponding one of the nozzles, and the plurality of channels arranged with one another, and an actuator formed as a partition wall which is shared with the adjacent channels and formed of a piezoelectric material, and the actuator causing ink in the channel to be injected out of the nozzle by changing the volume of the channel by shear deformation of the partition wall through the application of a drive signal; and a drive signal generating unit generating the drive signal containing a plurality of drive pulses for driving the actuator, the droplet injection apparatus controlling the driving of the recording head in such a way that an ink injection operation is sequentially performed by time division by dividing all the channels into two or more groups, each being formed of the channels away from one another with one or more channels placed therebetween, and applying the drive signal to each group, wherein the ink has a viscosity of less than 5.0×10^{-3} Pa·sec, the drive signal contains a first pulse formed as a rectangular wave that increases the volume of the channel and restores the volume to the original volume after a lapse of a given period of time and a second pulse formed as a rectangular wave that reduces the volume of the channel and restores the volume to the original volume after a lapse of a given period of time, and the ratio of a voltage Von of the first pulse to a voltage Voff of the second pulse is $0.5 \leq |Von/Voff| \leq 0.8$.

The pulse width of the first pulse can be 0.7 AL or more but 1.3 AL or less, and the ratio of the pulse width PWon of the first pulse to the pulse width PWoff of the second pulse can be $0.45 \leq |PWon/PWoff| \leq 0.55$.

A second aspect of the invention provides a method for driving a droplet injection apparatus including a recording head , including a plurality of nozzles injecting ink droplets, a plurality of channels, each communicating with a corresponding one of the nozzles, and the plurality of channels arranged with one another, and an actuator formed as a partition wall which is shared with the adjacent channels and formed of a piezoelectric material, and the actuator causing ink in the channel to be injected out of the nozzle by changing the volume of the channel by shear deformation of the partition wall through the application of a drive signal, and a drive signal generating unit generating the drive signal containing a plurality of drive pulses for driving the actuator, the droplet injection apparatus controlling the driving of the recording head in such a way that an ink injection operation is sequentially performed by time division by dividing all the channels into two or more groups, each being formed of the channels away from one another with one or more channels placed therebetween, and applying the drive signal to each group, wherein the ink has a viscosity of less than 5.0×10^{-3} Pa·sec, the drive signal contains a first pulse formed as a rectangular wave that increases the volume of the channel and restores the volume to the original volume after a lapse of a given period of time and a second pulse formed as a rectangular wave that reduces the volume of the channel and restores the volume to the original volume after a lapse of a given period of time, and the ratio of a voltage Von of the first pulse to a voltage Voff of the second pulse is $0.5 \leq |Von/Voff| \leq 0.8$. The pulse width of the first pulse can be 0.7 AL or more but 1.3 AL or less, and the ratio of the pulse width PWon of the first pulse to the pulse width PWoff of the second pulse can be $0.45 \leq |PWon/PWoff| \leq 0.55$.

[0017] According to the aspects of the invention, it is possible to provide a droplet injection apparatus and a method for driving the droplet injection apparatus, the apparatus and the method that can inject an ink droplet from a recording head with stability by stabilizing the vibration of the meniscus of a nozzle that does not perform injection, the nozzle adjacent to a nozzle that performs injection, when an ink droplet is injected from a recording head of shear mode type by time division driving by using low-viscosity ink, the recording head of shear mode type that causes shear deformation of a partition wall shared by adjacent channels as an actuator.

BRIEF DESCRIPTION OF THE DRAWINGS

[0018]

FIG. 1 is a diagram showing a schematic configuration of an ink-jet recording apparatus which is an application example of a droplet injection apparatus according to the invention;
FIGs. 2A and 2B are diagrams showing an example of a recording head forming the droplet injection apparatus in the invention, FIG. 2A being a perspective view showing the appearance of the recording head in cross section and FIG. 2B being a sectional view of the recording head viewed from the side thereof;
FIG. 3 is a diagram showing an example of a drive signal in the invention;
FIGs. 4A to 4C are diagrams illustrating the operation when the recording head performs ink injection;
FIGs. 5A to 5C are diagrams illustrating 3-cycle driving;
FIG. 6 is a timing chart of the drive signal at the time of 3-cycle driving;
FIG. 7 is a timing chart of the drive signal at the time of 3-cycle driving;
FIG. 8 is a graph showing the amount of extrusion of meniscus at the time of 3-cycle driving (driving on alternate channels) when different values of |Von/Voff| are adopted; and
FIG. 9 is a graph showing the amount of extrusion of meniscus of 3-cycle driving (driving on alternate channels) when two types of ink having different ink viscosities are used.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0019] Hereinafter, an embodiment of the invention will be described by using the drawings.

[0020] FIG. 1 is a diagram showing a schematic configuration of an ink-jet recording apparatus which is an application example of a droplet injection apparatus according to the invention.

[0021] In an ink-jet recording apparatus 1, a recording medium 10 is held by being sandwiched between a transport roller pair 22 of a transport mechanism 2 and is transported in a Y direction (a subscanning direction) shown in the drawing by a transport roller 21 which is driven and rotated by a transport motor 23.

[0022] Between the transport roller 21 and the transport roller pair 22, a recording head 3 is provided in such a way as to face a recording surface 10a of the recording medium 10. The recording head 3 is disposed and mounted on a carriage 5 in such a way that the nozzle surface thereof faces the recording surface 10a of the recording medium 10 and is electrically connected, via a flexible cable 6, to a drive signal generating section 100 (see FIGs. 4A to 4C) which is a drive signal generating unit provided in a drive circuit. The carriage 5 is provided in such a way that the carriage 5 can reciprocate, by an unillustrated driving unit along guide rails 4 that are put across the recording medium 10 in the width direction thereof, in an X-X' direction (a main scanning direction) shown in the drawing, the X-X' direction that is virtually perpendicular to the transport direction (the subscanning direction) in which the recording medium 10 is transported.

[0023] The recording head 3 moves above the recording surface 10a of the recording medium 10 in the X-X' direction shown in the drawing with the movement of the carriage 5 in the main scanning direction and injects an ink droplet out of a nozzle during this movement. In this way, the recording head 3 records a desired ink-jet image.

[0024] FIGs. 2A and 2B are diagrams showing an example of the recording head 3 forming the droplet injection apparatus in the invention, FIG. 2A being a perspective view showing the appearance of the recording head 3 in cross section and FIG. 2B being a sectional view of the recording head 3 viewed from the side thereof.

[0025] The recording head 3 includes a channel substrate 30. In the channel substrate 30, a large number of narrow groove-shaped channels 31 and partition walls 32 are arranged alternately with one another. On a top face of the channel substrate 30, a cover substrate 33 is provided in such a way as to cover all the channels 31. To the end faces of the channel substrate 30 and the cover substrate 33, a nozzle plate 34 is bonded, and the surface of the nozzle plate 34 forms a nozzle surface. An end of each channel 31 communicates with the outside via a nozzle 34a formed in the nozzle plate 34.

[0026] The other end of each channel 31 becomes gradually shallow with respect to the channel substrate 30 and communicates with a common channel 33a which is formed in the cover substrate 33 and shared by the channels 31. The common channel 33a is closed with a plate 35, and the common channel 33a and the channels 31 are supplied with ink through an ink feed pipe 35b via an ink supply port 35a formed in the plate 35.

[0027] Each partition wall 32 is formed of a piezoelectric material such as PZT which is an electromechanical converting unit, and functions as an actuator of the invention. Here, an example in which both an upper wall portion 32a and a lower wall portion 32b are formed of a piezoelectric material subjected to polarization treatment and the upper wall portion 32a and the lower wall portion 32b are opposite in polarization direction (indicated with arrows in FIG. 2B) is shown. However, a portion formed of a piezoelectric material subjected to polarization treatment may be only a portion with a reference character 32a, for example, and simply has to be at least part of the partition wall 32. The partition walls 32 and the channels 31 are arranged alternately with one another. Therefore, one partition wall 32 is shared by the channels 31 and 31 on both sides thereof.

[0028] In each channel 31, drive electrodes (not shown in FIGs. 2A and 2B) are formed from the wall surfaces of the partition walls 32 to the bottom face of the channel 31. When a drive signal of a predetermined voltage is applied to the drive electrodes sandwiching the partition wall 32 from the drive signal generating section 100 provided in the drive circuit, which will be described later, the partition wall 32 undergoes shear deformation at the bonded surface between the upper wall portion 32a and the lower wall portion 32b. As a result of the volume of the channel 31 being changed due to the shear deformation of the partition wall 32, a pressure wave is generated and pressure for injecting ink out of the nozzle 34a is provided to the ink in the channel 31. Therefore, the recording head 3 is a recording head of shear mode type in which the inside of the channel 31 surrounded with the channel substrate 30, the cover substrate 33, and the nozzle plate 34 forms a pressure generating chamber, the recording head of shear mode type that injects ink in the channel 31 out of the nozzle 34a by shear deformation of the partition wall 32.

[0029] In the invention, the ink in the channel 31 of the recording head 3 is low-viscosity ink having a viscosity of less than 5.0×10^{-3} Pa·sec. In normal times, the viscosity of ink is set at the viscosity at room temperature (25°C). However, it is known that the viscosity of ink has a temperature dependence, and there are cases in which the ink is used after the viscosity thereof is lowered by providing an unillustrated heating device in an ink supplying unit or the recording head 3 and increasing the temperature of the ink. In such a case, the viscosity of ink is a viscosity measured at a set temperature to which the ink used for injection is heated.

[0030] The drive signal generating section 100 provided in the drive circuit that is electrically connected to the recording head 3 via the flexible cable 6 generates a drive signal containing a plurality of drive pulses causing an ink droplet to be injected.

[0031] An example of the drive signal used in the invention is shown in FIG. 3.

[0032] The drive signal shown in Fig. 3 contains a first pulse Pa that is formed as a rectangular wave of a positive voltage (+Von) and increases the volume of the channel and restores the volume to the original volume after a lapse of a given period of time in a drive period T, and a second pulse Pb that is formed as a rectangular wave of a negative voltage (-Voff) and reduces the volume of the channel and restores the volume to the original volume after a lapse of a given period of time in the drive period T.

[0033] Incidentally, the given period of time which is the duration of time in which the volume of the channel is increased or reduced is represented as an AL (acoustic length). The AL corresponds to 1/2 of an acoustic resonance period of a pressure wave in the channel. The AL is obtained as a pulse width at which the flying speed of an ink droplet becomes maximum when the speed of an ink droplet that is injected at the time of application of a drive pulse of a rectangular wave to the drive electrode is measured and the pulse width of the rectangular wave is varied by making the voltage value of the rectangular wave constant.

[0034] Moreover, the pulse is a rectangular wave of a constant-voltage peak value. When 0V is assumed to be 0 % and a peak value voltage is assumed to be 100%, the pulse width is defined as the time between the rising edge 10% from 0V and the falling edge 10% from the peak value voltage.

[0035] Furthermore, the rectangular wave refers to a waveform whose rising edge time and falling edge time between 10% and 90% of a voltage fall within 1/2 of the AL, preferably 1/4 of the AL.

[0036] In particular, in the recording head 3 of shear mode type, since an ink droplet is injected out of the nozzle 34a by using the resonance of the pressure wave generated in the channel 31, it is possible to inject the ink droplet more efficiently by using the rectangular wave.

[0037] Moreover, in the recording head 3 of shear mode type, since the meniscus responds quickly to the application of a drive signal formed as a rectangular wave, it is possible to keep the drive voltage low. In general, since a voltage is always applied to the recording head 3 irrespective of whether injection is performed or not, a low drive voltage is important in reducing heat generation of the head and injecting an ink droplet with stability.

[0038] Furthermore, since the rectangular wave can be generated easily by using a simple digital circuit, the circuit configuration can be simplified as compared to a case in which a trapezoidal wave having an inclined wave is used.

[0039] Next, an ink injection operation performed when the recording head 3 is driven by using the drive signal shown in FIG. 3 will be described by using FIGs. 4A to 4C. FIGs. 4A to 4C show part of the cross-section of the recording head 3 obtained by cutting the recording head 3 in a direction perpendicular to the length direction of the channel 31.

[0040] FIGs. 4A to 4C show three adjacent channels 31 (31A, 3 1 B, and 31 C) of a large number of channels 31. One end of each channel 31 connects to the nozzle 34a formed in the nozzle plate 34 shown in FIGs. 2A and 2B and the other end connects to an unillustrated ink tank by the ink tube 35b via the ink supply port 35a. In addition, on the surfaces of the partition walls 32 facing the insides of the channels 31, drive electrodes 36A, 36B, and 36C extending toward the bottom faces of the channels 31 are formed in such a way as to be attached firmly to the surfaces of the partition walls 32. The drive electrodes 36A, 36B, and 36C are electrically connected to the drive signal generating section 100.

[0041] When the drive signal shown in FIG. 3 is applied to the drive electrodes 36A, 36B, and 36C which are formed in such a way as to be attached firmly to the surfaces of partition walls 32A, 32B, 32C, and 32D by control exercised by the drive signal generating section 100, an ink droplet is injected out of the nozzle 34a by the operation described below as an example.

[0042] First, when the drive signal is not applied to the drive electrodes 36A, 36B, and 36C, the partition walls 36A, 36B, and 36C are not deformed. In a state shown in FIG. 4A, when the drive electrodes 36A and 36C are grounded and the drive signal shown in FIG. 3 is applied to the drive electrode 36B, an electric field in a direction perpendicular to the polarization direction of the piezoelectric material forming the partition walls 32B and 32C is generated by the first pulse Pa. As a result, in the partition walls 32B and 32C, shear deformation appears in the bonded surfaces of the upper and lower partition walls 32a and 32b, and, as shown in FIG. 4B, the partition walls 32B and 32C are deformed outwardly and increase the volume of the channel 31 B. This generates a negative pressure in the channel 3 1 B and allows the ink to flow thereinto (Draw).

[0043] Since the pressure in the channel 31 B is inverted once every AL, when this state is maintained for 1 AL, the pressure in the channel 31 B is inverted and becomes a positive pressure. When the drive electrode 36B is grounded at this time, the partition walls 32B and 32C return from expansion positions shown in FIG. 4B to neutral positions shown in FIG. 4A, and a high pressure is applied to the ink in the channel 31 B (Release).

[0044] Then, when the second pulse Pb is applied to the drive electrode 36B immediately after the falling edge of the first pulse Pa, as shown in FIG. 4C, the partition walls 32B and 32C are deformed in opposite directions and reduce the volume of the channel 32B. Since the second pulse Pb is applied at a time point at which the pressure in the channel 31B is inverted and becomes a positive pressure after the application of the first pulse Pa, the positive pressure wave caused by a reduction of the volume of the channel 32B is added thereto. This increases the injection pressure (the injection speed) of the ink droplet and makes it possible to obtain the most efficient injection power. As a result, the drive voltage can be lowered and therefore power consumption can be reduced.

[0045] As a result of the channel 31 B contracting due to the application of the second pulse Pb, a higher pressure is applied to the ink with which the channel 31B is filled (Reinforce) and an ink column is pushed out of the nozzle. When the potential of the second pulse Pb is returned to 0 after 2 AL after the application of the second pulse Pb, the channel 3 1 B returns to the neutral position of FIG. 4A.

[0046] In the above description, the pulse width PWon of the first pulse Pa is 1 AL. However, the pulse width PWon of the first pulse Pa in the invention simply has to fall within a range of 0.7 AL or more but 1.3 AL or less, which is in the neighborhood of 1 AL. Moreover, when the ratio of PWon to PWoff (PWon/PWoff) is $0.45 \leq |PWon/PWoff| \leq 0.55$, it is possible to stabilize the meniscus surface after injection efficiently.

[0047] As described above, in the recording head 3 having the plurality of channels 31 partitioned by the partition walls 32 at least part of which is formed of a piezoelectric material, since the adjacent channels 31 share the partition wall 32, when the partition walls 32 of one channel 31 perform an injection operation, channels 31 adjacent to this channel 31 are affected by this operation. Therefore, in general, drive control is performed in such a way that an ink injection operation is performed sequentially by time division by dividing all the channels 31 into two or more groups by treating channels 31 which are separated from each other with one or more channels 31 placed between them, the channels 31 of the plurality of channels 31, as one group and then applying the drive signal to each group from the drive signal generating section 100. In particular, when a solid image is output as a result of all the channels 31 being driven, a so-called 3-cycle driving method is performed by which injection is performed by dividing the channels 31 into three phases by selecting the channel 31 at intervals of 2 channels.

[0048] An injection operation by such 3-cycle driving will be further described by using FIGs. 5A to 5C. In an example shown in FIGs. 5A to 5C, a description will be given with the assumption that the recording head includes nine channels 31: A1, B1, C1, A2, B2, C2, A3, B3, and C3. Here, the nozzle is not shown in the drawing. Moreover, a timing chart of a drive signal which is applied to drive the channels 31 of groups A, B, and C is shown in FIG. 6.

[0049] First, when the drive signal shown in FIG. 3 is applied to the drive electrode of each channel of the group A (A1, A2, and A3) and the drive electrodes of the channels on both sides thereof are grounded, only the partition walls of each channel of the group A from which an ink droplet is to be injected undergo shear deformation as described by using FIGs. 4A to 4C, and an ink droplet is injected out of the nozzle of each channel 31 of the group A (A cycle).

[0050] Next, when the drive signal shown in FIG. 3 is applied to the drive electrode of each channel of the group B (B1, B2, and B3) and the drive electrodes of the channels on both sides thereof are grounded, only the partition walls of each channel of the group B from which an ink droplet is to be injected undergo shear deformation as described by using FIGs. 4A to 4C, and an ink droplet is injected out of a nozzle of each channel of the group B (B cycle).

[0051] Furthermore, when the drive signal shown in FIG. 3 is applied to the drive electrode of each channel of the group C (C1, C2, and C3) and the drive electrodes of the channels on both sides thereof are grounded, only the partition walls of each channel of the group C from which an ink droplet is to be injected undergo shear deformation as described by using FIGs. 4A to 4C, and an ink droplet is injected out of a nozzle of each channel of the group C (C cycle).

[0052] The above description deals with a case in which an ink droplet is injected from all the channels 31 of each group as in a case in which a solid image is printed, for example. However, depending on printing data, there are cases in which, even when the group A is being driven, the channel A2 in FIG. 5A, for example, becomes a non-injection channel. If the channels 31 (C1 and B2) on both sides of the channel A2 are injection channels, an increase in the amount of extrusion of meniscus in the nozzle of the channel 31 (A2) becomes a problem.

[0053] Such deformation of the partition wall 32 of the recording head 3 of shear mode type appears due to a difference in voltage applied to the drive electrodes provided on both sides of the partition wall 32 in such a way as to sandwich the partition wall 32. Therefore, when the drive signal shown in FIG. 3 is used, the same operation can also be performed by grounding the drive electrode in the channel 31 that performs injection of an ink droplet and applying the second pulse Pb to the drive electrodes in the channels 31 on both sides thereof as a pulse of a positive voltage (+Voff) as shown in FIG. 7 instead of applying the second pulse Pb which is a negative voltage (-Voff) to the drive electrode in the channel 31 that performs injection of an ink droplet.

[0054] For example, when the channels 31 of the group A are operated as injection channels, it is necessary simply to ground the drive electrodes in the channels 31 of the group A immediately after the falling edge of the first pulse Pa after applying the first pulse Pa (+Von) to the drive electrodes in the channels 31 of the group A and at the same time applying the second pulse Pb (+Voff) to the drive electrodes in the channels 31 of the group B and the group C on both sides of the channels 31 of the group A, the channels 31 of the group B and the group C sharing the partition walls with the channels 31 of the group A. This method is desirable because it is possible to perform driving only with a positive voltage.

[0055] In the invention, it is important to make the ratio of the voltage Von of the first pulse Pa to the voltage Voff of the second pulse Pb (Von/Voff) satisfy $0.5 \leq |Von/Voff| \leq 0.8$.

[0056] By setting |Von/Voff| at 0.8 or less as described above, the amount of extrusion of meniscus from the nozzle is reduced, making it possible to reduce the risk of sucking the air into the nozzle. The reason is considered as follows. Since drawing (Draw) of the driven channel that injects an ink droplet becomes relatively small, the amount of extrusion of meniscus of the adjacent channel by Draw is reduced.

[0057] FIG. 8 depicts the time change in the amount of extrusion of meniscus of a specific non-driven channel of the group A when 3-cycle driving (driving on alternate channels) is performed by using ink having a viscosity of 3.8×10^{-3} Pa·sec. As in the case shown in FIG. 9, depicted here is a specific non-injection channel (an odd-numbered channel) of the group A when even-numbered channels of the channels are driven as injection channels that perform ink injection in the order of the group A, the group B, and the group C (A cycle → B cycle → C cycle). As a result, when adjacent even-numbered channels (even-numbered ch) of the group B are driven to perform injection, as compared to a case in which |Von/Voff| = 2, the amount of extrusion of meniscus when |Von/Voff| = 0.67 is reduced.

[0058] Moreover, by setting |Von/Voff| at 0.5 or more, it is possible to reduce heat generation and the load on an IC due to a decrease in driving efficiency.

EXAMPLES

[0059] Hereinafter, the advantages of the invention will be illustrated based on examples.

[0060] A stable speed upper limit and generation of satellite spray when 3-cycle driving was performed by changing the ratio of the voltage Von of the first pulse to the voltage Voff of the second pulse (|Von/Voff|) in the drive signal shown in FIG. 3 by using two types of ink, which will be described later, in the recording head of shear mode type shown in FIGs. 2A and 2B were evaluated.

[0061] Incidentally, the recording head had 256 nozzles, the nozzle diameter was 30 μm, AL was 5.6 μs, the pulse width PWon of the first pulse of the drive signal was 5.6 μs (1 AL), the pulse width PWoff of the second pulse was 11.2 μs (2 AL), and the drive period T was 28 μs (5 AL).

[0062] The stable speed upper limit means an injectable maximum flying speed (m/s) observed immediately before injection of an ink droplet becomes impossible when the air is sucked into the nozzle as a result of the flying speed being increased by increasing the voltage without changing |Von/Voff| at each voltage ratio |Von/Voff|. The stable speed upper limit was obtained by measuring the flying speed by, in addition to the normal all-channel driving, a driving pattern (switching driving) in which driving of only even-numbered channels (2 (B cycle channel), 4 (A cycle channel), 6 (C cycle channel), 8 (B cycle channel) ...) and driving of only odd-numbered channels (1 (A cycle channel), 3 (C cycle channel), 5 (B cycle channel), 7 (A cycle channel) ...) are switched once every a predetermined time (1 sec) and adopting a lower flying speed in the two evaluations.

[0063] Incidentally, a higher stable speed upper limit value is preferable because the higher the stable speed upper limit value, the wider the flying speed range of an ink droplet. Since an absence of injection causes serious image degradation, it is desirable that there is at least a difference of the order of 1.5 m/s between the speed which is actually used and the stable speed upper limit. Here, it is assumed that an image is recorded and formed by injecting an ink droplet at a flying speed of 6 m/s, and the apparatus (the invention) can be used with no trouble as long as the stable speed upper limit is 7.5 m/s or more.

[0064] The generation of satellite spray was evaluated as follows. An ink droplet was injected on recording paper by setting the flying speed of the ink droplet at 6 m/s, and the image quality of formed evaluation images including the above-described switching driving was visually checked by 10 people.

[0065] The criteria for evaluation are as follows.

Few: 0 to 1 out of 10 people judged that satellite spray was noticeable
Medium: 2 to 4 out of 10 people judged that satellite spray was noticeable
Many: 5 or more out of 10 people judged that satellite spray was noticeable

Types of ink

[0066]

Ink 1: Viscosity 3.8×10^{-3} Pa·sec
Surface tension 38×10^{-3} $N\cdot m^{-1}$
Ink 2: Viscosity 4.3×10^{-3} Pa·sec
Surface tension 56×10^{-3} $N\cdot m^{-1}$

[0067] The measurement results obtained when the ink 1 was used are shown in Table 1, and the measurement results obtained when the ink 2 was used are shown in Table 2.

[Table 1]

Ink 1			
	Von/Voff	Stable Speed Upper Limit (m/s)	Generation of Satellite Spray
Comparative Example 1	0.4	7.3	Medium
Example 1	0.5	8.2	Few
Example 2	0.67	7.7	Few
Example 3	0.8	7.6	Few
Comparative Example 2	1.4	6.4	Few
Comparative Example 3	2	6.2	Few

[Table 2]

Ink 2			
	Von/Voff	Stable Speed Upper Limit (m/s)	Generation of Satellite Spray
Comparative Example 4	0.4	8	Many
Example 4	0.5	9.4	Medium
Example 5	0.67	9.7	Few
Example 6	0.8	8.8	Few
Comparative Example 5	1.4	7.3	Few
Comparative Example 6	2	7.3	Few

[0068] As is clear from Tables 1 and 2, with both the ink 1 and the ink 2, when $0.5 \leq |Von/Voff| \leq 0.8$ (Examples 1 to 6), desirable results indicating that the stable speed upper limit is 7.5 m/s or more and the generation of satellite spray is few are obtained.

[0069] In Comparative Examples 2, 3, 5, and 6 in which the value of |Von/Voff| is greater than 0.8, the stable speed upper limit is low. This is because no injection is performed when an ink droplet speed is increased at the time of switching driving due to large meniscus vibration.

[0070] On the other hand, as in Comparative Examples 1 and 4, when the value of |Von/Voff| is less than 0.5, the stable speed upper limit also becomes low. This is caused by a reduction in drive efficiency because the lower |Von/Voff|, the smaller drawing of the ink in the first pulse which is an expansion pulse. That is, when the drive efficiency is low, a higher voltage is required to perform injection at high speed, but the stable speed upper limit is limited due to a rated value of a drive IC and the problem of heat generation. This problem noticeably arises when the value of |Von/Voff| is less than 0.5.

[0071] Moreover, when the value of |Von/Voff| becomes less than 0.5, the generation of satellite spray is increased in both the ink 1 and the ink 2. When the value of |Von/Voff| is reduced, the pulse voltage Voff becomes relatively high. This means that cancellation of the pressure wave is increased. As a result, the impact of pressure caused when the ink droplet is torn is increased and the generation of satellite spray is increased.

[0072] Based on the above results thus obtained, desirable ink flight characteristics are obtained when $0.5 \leq |Von/Voff| \leq 0.8$. When |Von/Voff| = 0.67, especially desirable flight characteristics of an ink droplet are obtained.

REFERENCE EXAMPLES

[0073] For reference purposes, the stable speed upper limit was measured in the same manner by using ink 3 and ink 4, which will be described below, by adopting the recording head and the driving method described above. The measurement results are shown in Table 3.

[0074]

Ink 3: Viscosity 5.7×10^{-3} Pa·sec
Surface tension 41×10^{-3} $N\cdot m^{-1}$
Ink 4: Viscosity 7.2×10^{-3} Pa·sec
Surface tension 39×10^{-3} $N\cdot m^{-1}$

[Table 3]

	Von/Voff	Stable Speed Upper Limit (m/s)	
		Ink 3	Ink 4
Comparative Example 7	0.4	8	8.2
Example 7	0.5	8.8	9
Example 8	0.67	9.6	9.3
Example 9	0.8	9.5	9.2
Comparative Example 8	1	9	9.2
Comparative Example 9	2	8.6	9

[0075] With the ink 3 and the ink 4, due to high viscosity thereof, remarkable destabilization does not appear at the time of switching driving. As a result, the stable speed upper limit is almost constant irrespective of the value of |Von/Voff|.

[0076] The above results reveal that injection destabilization at the time of switching driving becomes remarkable when the ink viscosity is less than 5.0×10^{-3} Pa·sec, and setting the ratio of the voltage Von of the first pulse to the voltage Voff of the second pulse at $0.5 \leq |Von/Voff| \leq 0.8$ is effective in preventing this destabilization.

Claims

1. A droplet injection apparatus comprising:

a recording head ,including

a plurality of nozzles injecting ink droplets, a plurality of channels, each communicating with a corresponding one of the nozzles, and the plurality of channels arranged with one another, and
an actuator formed as a partition wall which is shared with the adjacent channels and formed of a piezoelectric material, and the actuator causing ink in the channel to be injected out of the nozzle by changing the volume of the channel by shear deformation of the partition wall through the application of a drive signal; and
a drive signal generating unit generating the drive signal containing a plurality of drive pulses for driving the actuator,
the droplet injection apparatus controlling the driving of the recording head in such a way that an ink injection operation is sequentially performed by time division by dividing all the channels into two or more groups, each being formed of the channels away from one another with one or more channels placed therebetween, and applying the drive signal to each group,
wherein
the ink has a viscosity of less than 5.0×10^{-3} Pa·sec,
the drive signal contains a first pulse formed as a rectangular wave that increases the volume of the channel and restores the volume to the original volume after a lapse of a given period of time and a second pulse formed as a rectangular wave that reduces the volume of the channel and restores the volume to the original volume after a lapse of a given period of time, and
the ratio of a voltage Von of the first pulse to a voltage Voff of the second pulse is $0.5 \leq |Von/Voff| \leq 0.8$.

2. The droplet injection apparatus according to claim 1, wherein

the pulse width of the first pulse is 0.7 AL or more but 1.3 AL or less, and
the ratio of the pulse width PWon of the first pulse to the pulse width PWoff of the second pulse is $0.45 \leq |PWon/PWoff| \leq 0.55$.

3. A method for driving a droplet injection apparatus including

a recording head ,including
a plurality of nozzles injecting ink droplets, a plurality of channels, each communicating with a corresponding one of the nozzles, and the plurality of channels arranged with one another, and an actuator formed as a partition wall which is shared with the adjacent channels and formed of a piezoelectric material, and the actuator causing ink in the channel to be injected out of the nozzle by changing the volume of the channel by shear deformation of the partition wall through the application of a drive signal, and
a drive signal generating unit generating the drive signal containing a plurality of drive pulses for driving the actuator,
the droplet injection apparatus controlling the driving of the recording head in such a way that an ink injection operation is sequentially performed by time division by dividing all the channels into two or more groups, each being formed of the channels away from one another with one or more channels placed therebetween, and applying the drive signal to each group,
wherein
the ink has a viscosity of less than 5.0×10^{-3} Pa·sec,
the drive signal contains a first pulse formed as a rectangular wave that increases the volume of the channel and restores the volume to the original volume after a lapse of a given period of time and a second pulse formed as a rectangular wave that reduces the volume of the channel and restores the volume to the original volume after a lapse of a given period of time, and
the ratio of a voltage Von of the first pulse to a voltage Voff of the second pulse is $0.5 \leq |Von/Voff| \leq 0.8$.

4. The method for driving a droplet injection apparatus according to claim 3, wherein

the pulse width of the first pulse is 0.7 AL or more but 1.3 AL or less, and
the ratio of the pulse width PWon of the first pulse to the pulse width PWoff of the second pulse is $0.45 \leq |PWon/PWoff| \leq 0.55$.

FIG. 1

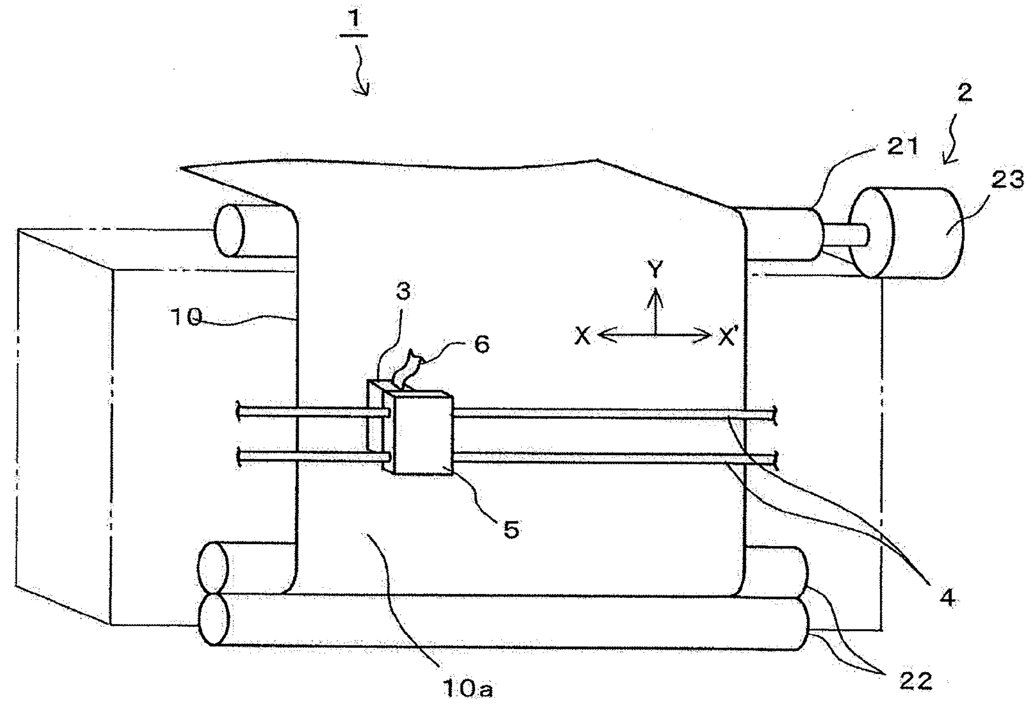


FIG. 2

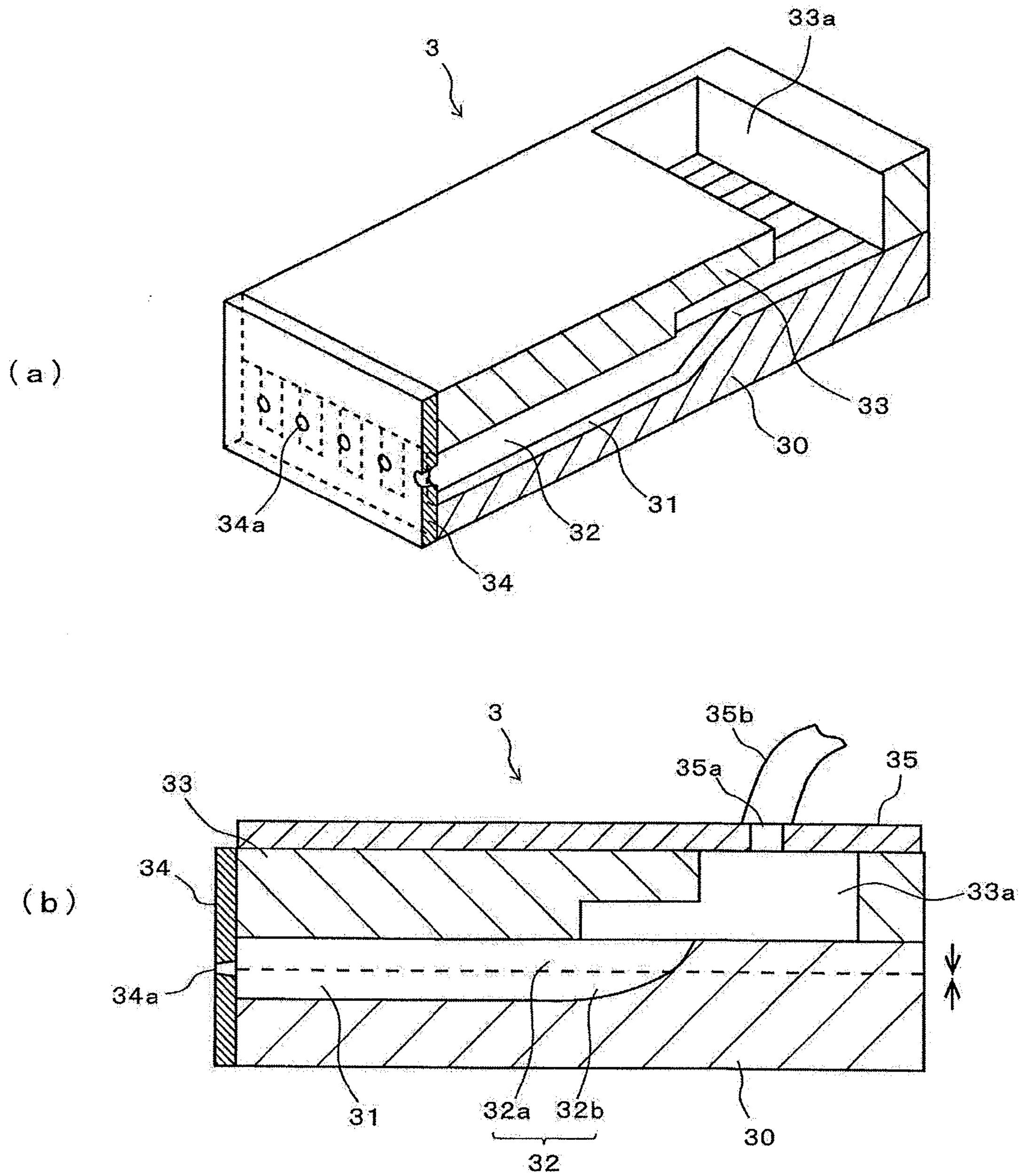

(a)
3
33a
33
30
31
32
34a
34
(b)
3
35b
35a
35
33
34
33a
34a
31
32a
32b
32
30

FIG. 3

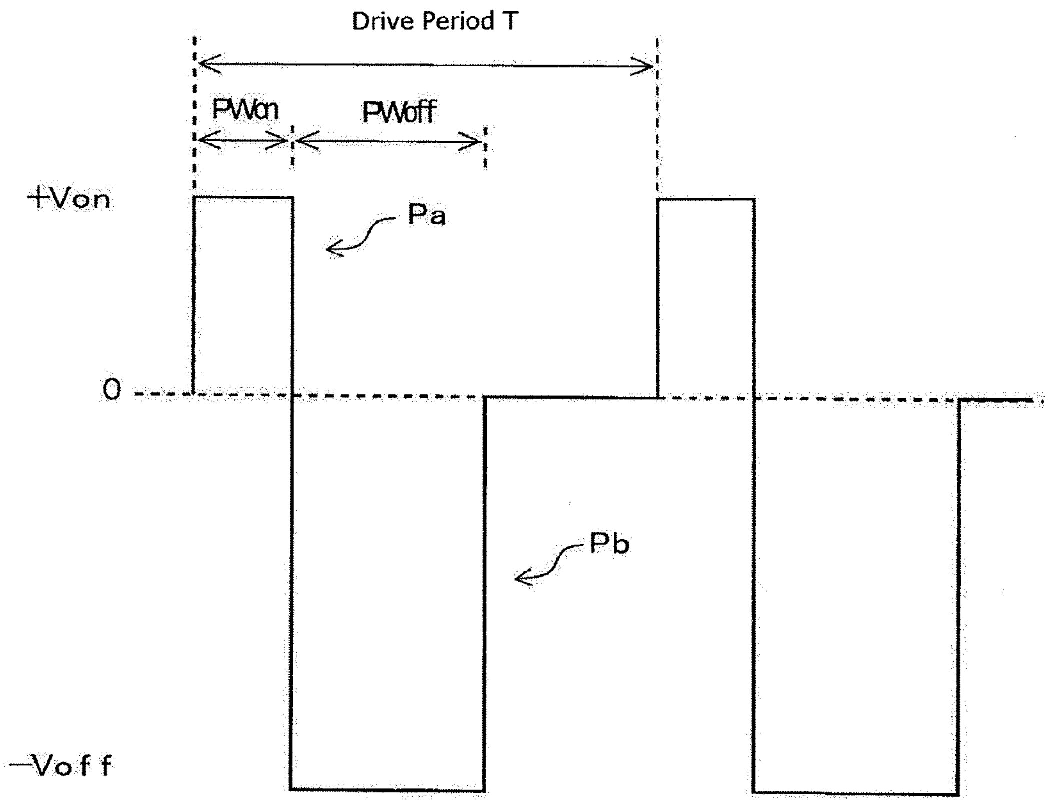
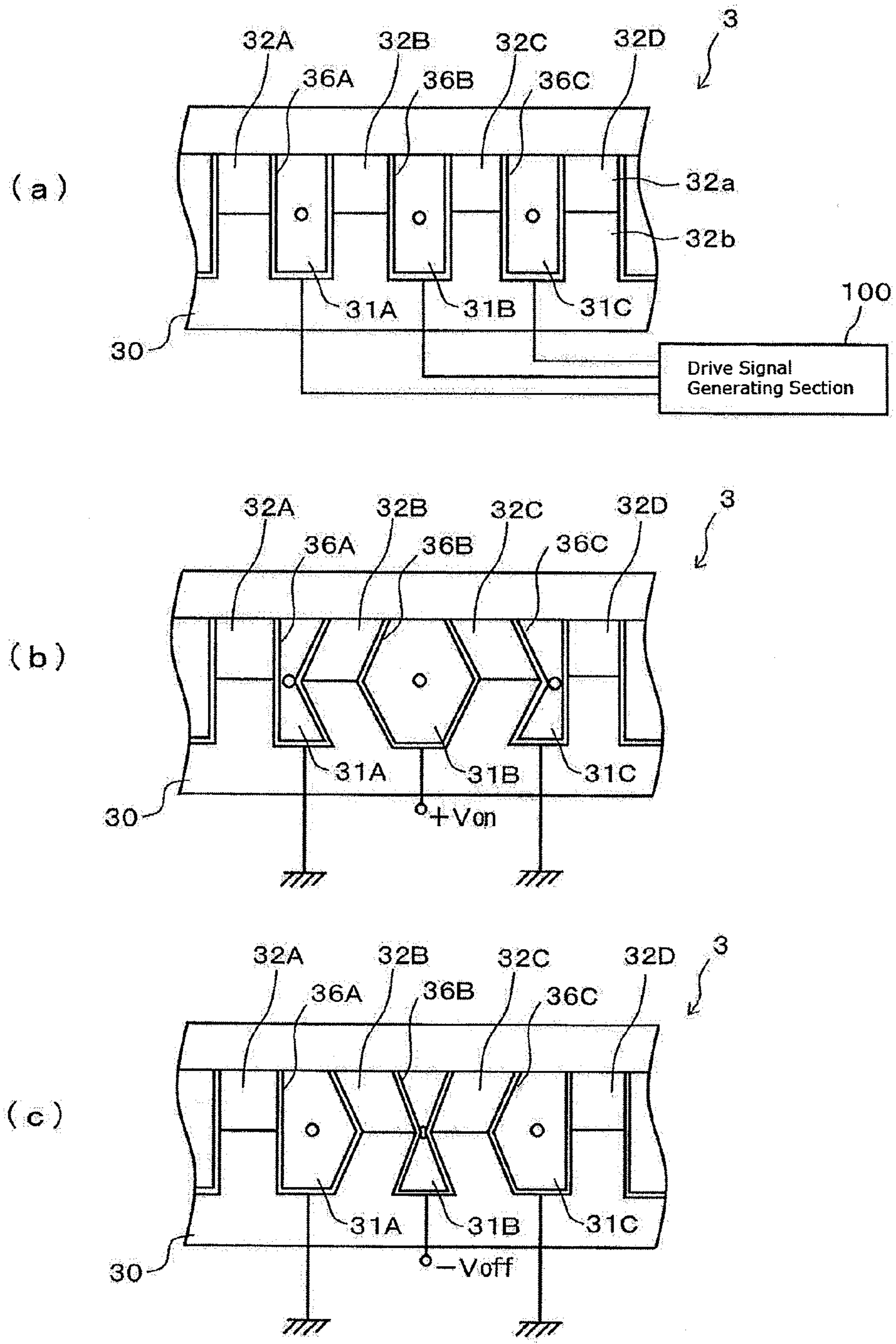


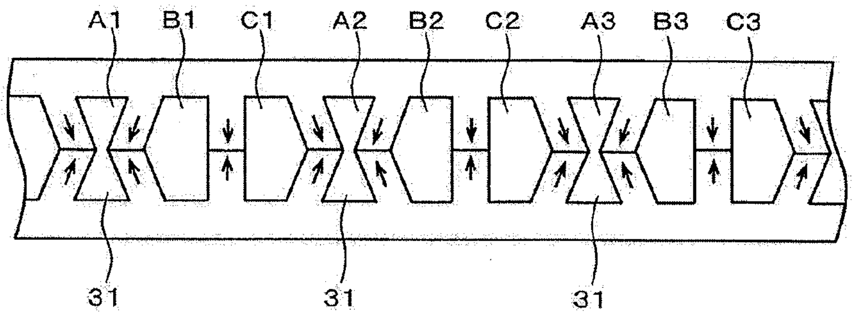
FIG. 4



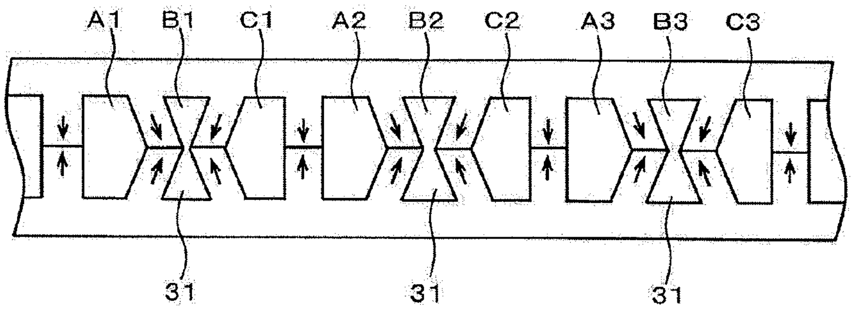
(a)
32A
32B
32C
32D
3
36A
36B
36C
32a
32b
31A
31B
31C
100
30
Drive Signal Generating Section
(b)
32A
32B
32C
32D
3
36A
36B
36C
31A
31B
31C
30
+Von
(c)
32A
32B
32C
32D
3
36A
36B
36C
31A
31B
31C
30
−Voff

FIG. 5

(a)


A1
B1
C1
A2
B2
C2
A3
B3
C3
31
31
31

(b)


A1
B1
C1
A2
B2
C2
A3
B3
C3
31
31
31

(c)

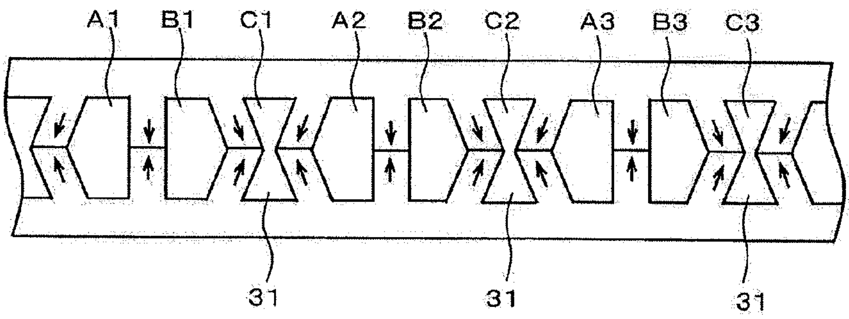

A1
B1
C1
A2
B2
C2
A3
B3
C3
31
31
31

FIG. 6

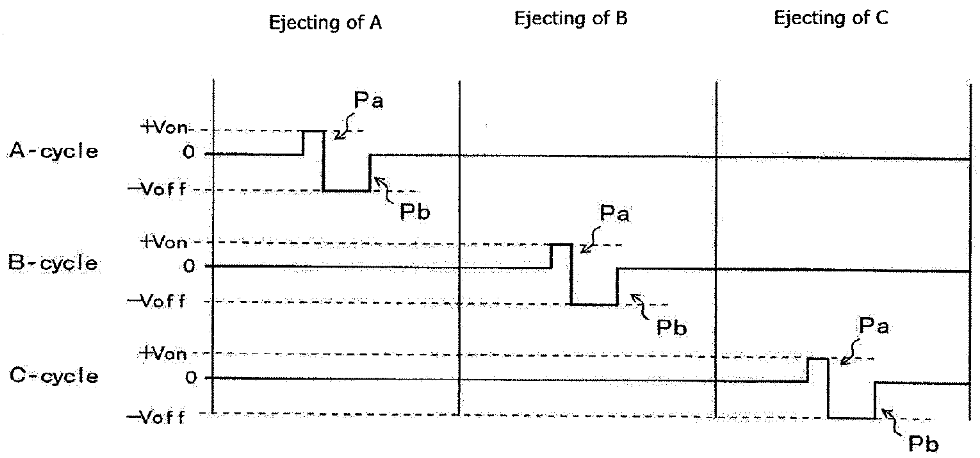

Ejecting of A
Ejecting of B
Ejecting of C
A-cycle
B-cycle
C-cycle
+Von
0
-Voff
Pa
Pb

FIG. 7

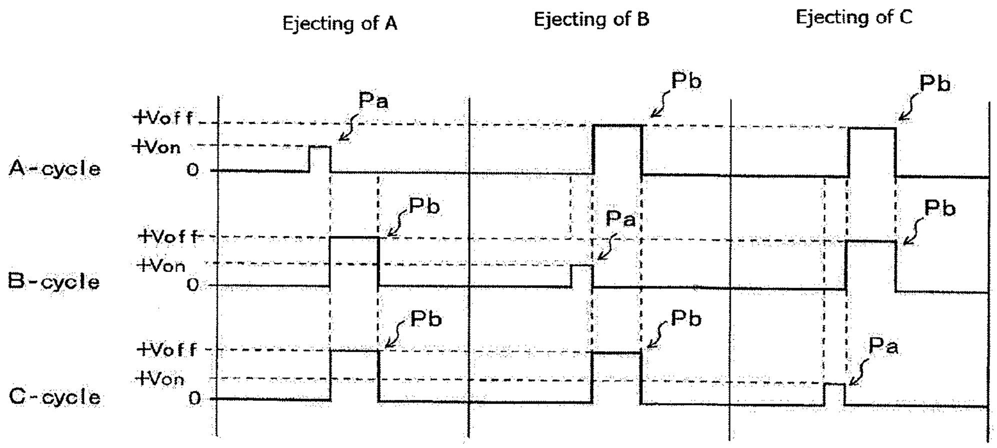

Ejecting of A
Ejecting of B
Ejecting of C
A-cycle
B-cycle
C-cycle
+Voff
+Von
0
Pa
Pb

FIG. 8

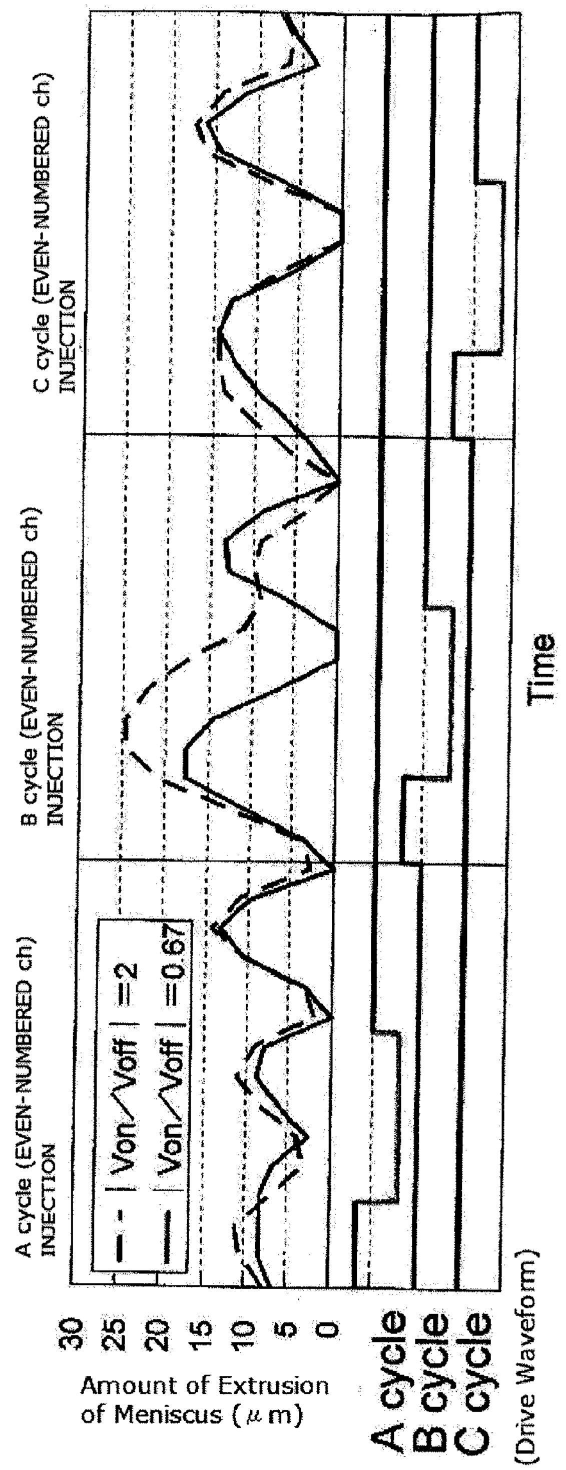
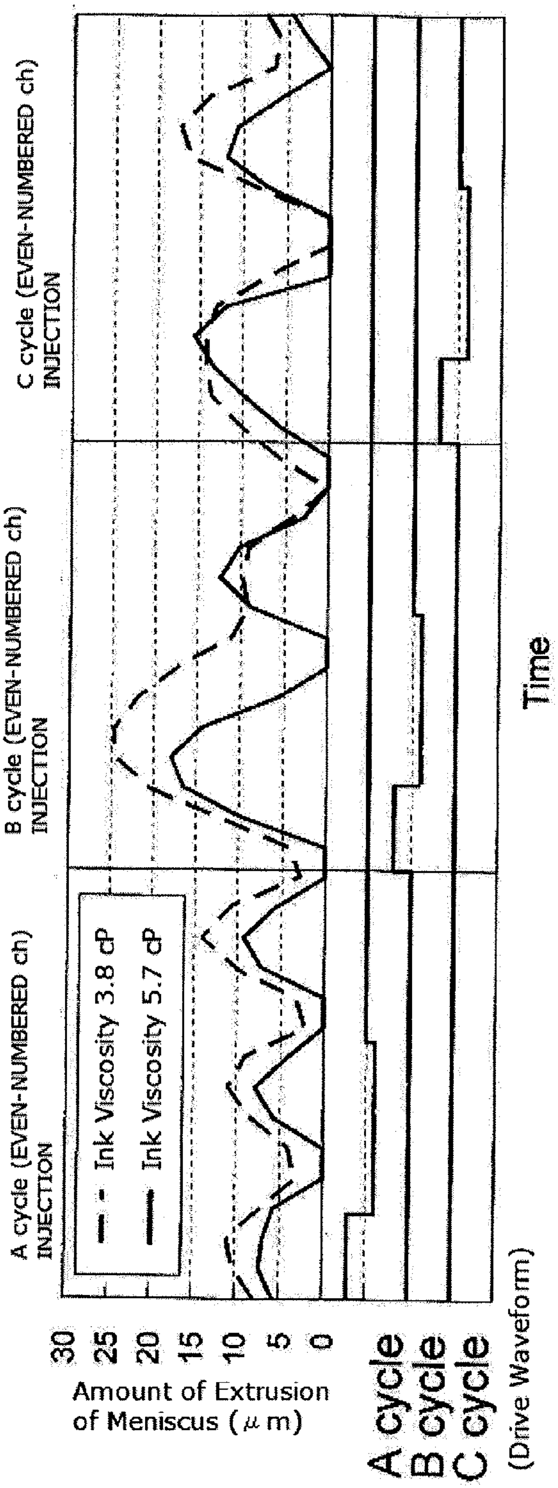

A cycle (EVEN-NUMBERED ch) INJECTION
B cycle (EVEN-NUMBERED ch) INJECTION
C cycle (EVEN-NUMBERED ch) INJECTION
|Von/Voff| =2
|Von/Voff| =0.67
30
25
20
15
10
5
0
Amount of Extrusion of Meniscus (μm)
A cycle
B cycle
C cycle
(Drive Waveform)
Time

FIG. 9


A cycle (EVEN-NUMBERED ch) INJECTION
B cycle (EVEN-NUMBERED ch) INJECTION
C cycle (EVEN-NUMBERED ch) INJECTION
Ink Viscosity 3.8 cP
Ink Viscosity 5.7 cP
30
25
20
15
10
5
0
Amount of Extrusion of Meniscus (μm)
A cycle
B cycle
C cycle
(Drive Waveform)
Time

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EUROPEAN SEARCH REPORT

Application Number
EP 12 19 9189

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The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
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